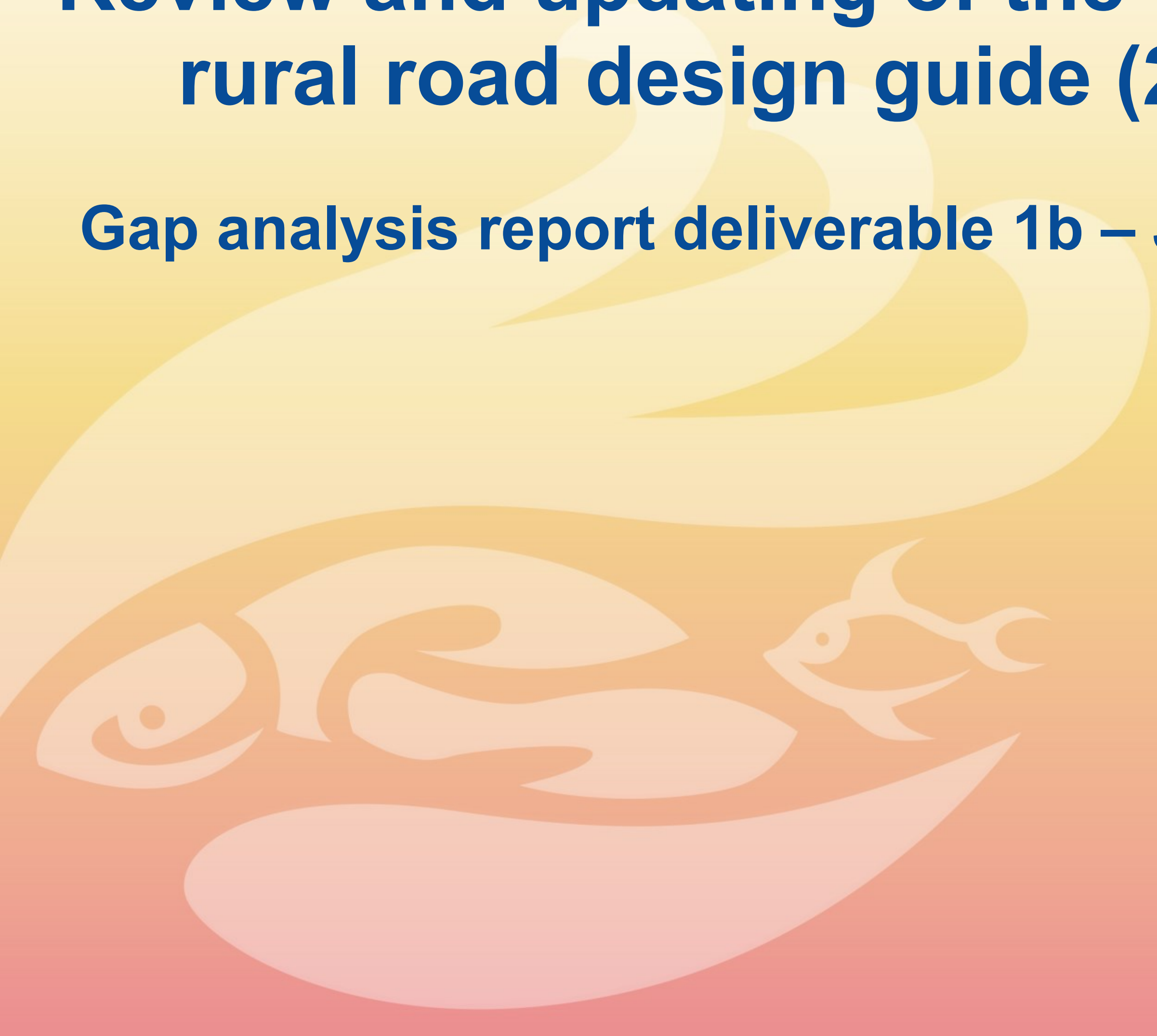
Review and updating of the Vanuatu rural road design guide (2017)

Gap analysis report deliverable 1b – June 2023



30 SPREP PROE

Sustainable, transformative and resilient for a Blue Pacific

7Dee Consult

Review and Updating of the Vanuatu Rural Road Design Guide (2017)

Gap Analysis Report
Deliverable 1b

18 June 2023

SPREP
Secretariat of the Pacific Regional Environment Programme

Contract

This report has been produced as **Deliverable 1b** under Services Agreement AP_3/28/2 2022/025 signed between the Secretariat of the Pacific Regional Environment Programme (SPREP) and Robert Paul Hardy (trading as 7Dee Consult) on 14 December 2022.

Document Version Control

Version	Effective Date	Description of Version/Revision	Prepared by	Reviewed by
1.0	18 June 2023	First Submission for SPREP and PWD Review	Robert Hardy	SPREP and PWD

Disclaimer

This report (including any enclosures and attachments) has been prepared for the exclusive use and benefit of SPREP and the Government of Vanuatu and is to be used solely for the purpose for which it is provided. Unless the author provides express prior written consent, no part of this report should be reproduced, distributed or communicated to any external third party. The author does not accept any liability to third parties if this report is used for an alternative purpose to that for which it is intended.

Robert Hardy
United Kingdom, June 2023

CONTENTS

1. INTRODUCTION

1.1 Introduction

The objective of this Gap Analysis Report is to articulate findings from an international literature review and benchmarking activity in relation to the identification of climate resilience issues and gaps in the current version of Vanuatu road design guidance. This gap analysis draws upon a series of input documents to develop a log of gaps and issues which need to be addressed in the new design guidance to be developed under this project. The log is limited to gaps and issues which relate to improving the resilience of Vanuatu's road network.

The report also draws upon the issues and gaps identified through the stakeholder consultations reported in Deliverable 1a, the Inception and Stakeholder Consultation Report.

1.2 Structure of this Report

One of the key comments received from PWD stakeholders on the existing Vanuatu Rural Road Design Guidance (VRRDG) is that it does not follow a logical design flow. The general consensus was that the guide would be improved if designers are taken through a step-by-step approach to the design of a new or upgraded road. At this stage a basic design methodology has been adopted a shown in Figure 1 below.

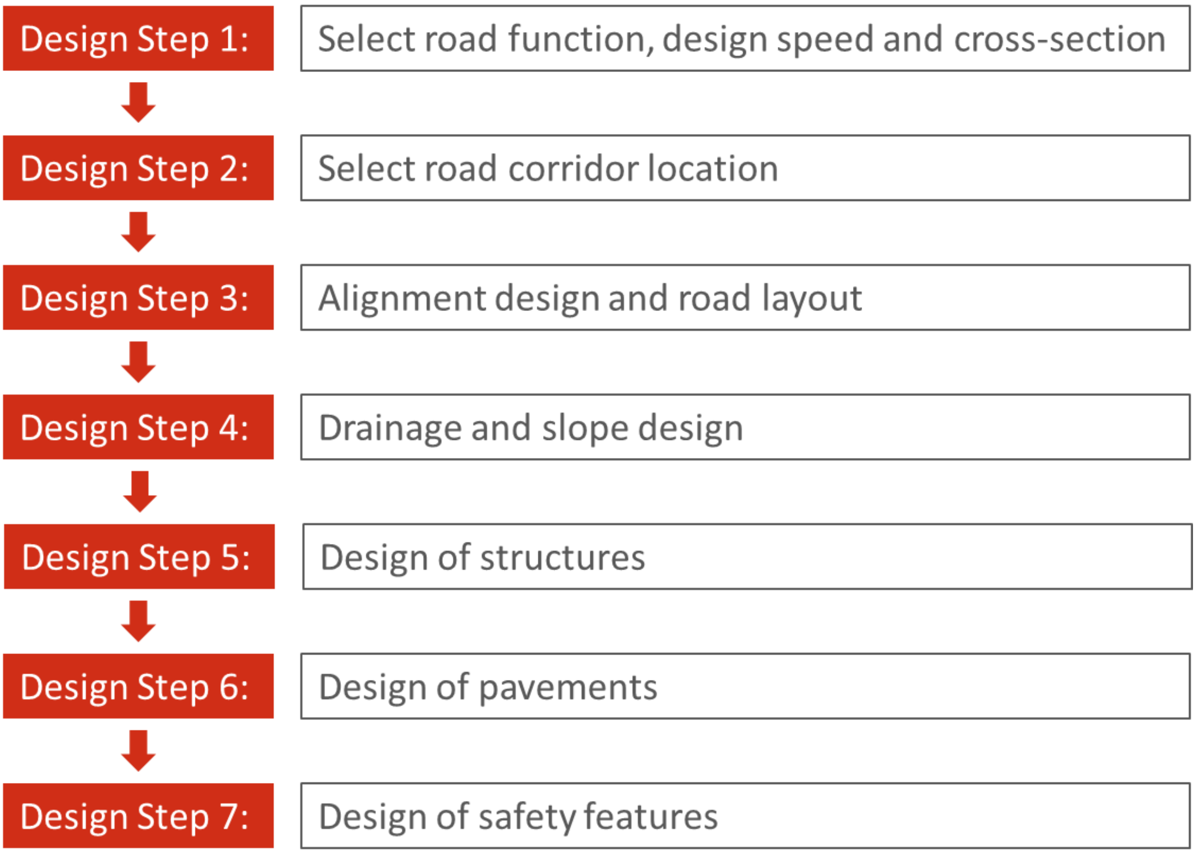


Figure 1: Road Design Methodology

This change in order of design stages is important because it will require designers to consider drainage ahead of the design of pavement. This is important in a Vanuatu setting because almost all cyclone damage to the road network is caused by storm damage at road/watercourse interfaces. Ensuring drainage works effectively is the key to improving road asset resilience.

The new design guide for Vanuatu will be structured to follow these design stages. It is therefore useful to log all gaps and issues into groups which will easily translate into the revised design guide structure. The process adopted within this report is shown diagrammatically in Figure 2 below.

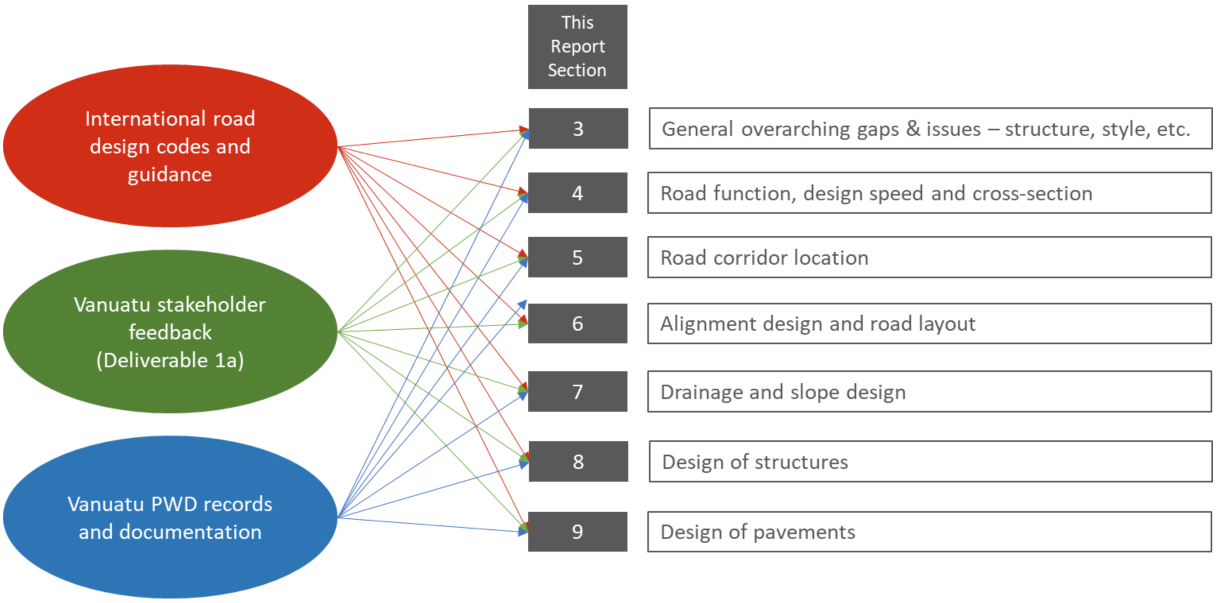


Figure 2: Report Development Structure

As can be seen, each section of the report draws upon three key sources of information to identify gaps and issues which need to be addressed to develop a new climate-resilient road design guide for Vanuatu. These are:

- International design codes and other relevant international guidance;
- Vanuatu stakeholder feedback (as reported in Deliverable 1a), and
- Vanuatu PWD records and documentation.

The new road design guide will include a final section on the design of road safety features, but this is not included in the gap and issues log as changing climate conditions are unlikely to have a significant impact on this part of the design process.

1.3 Structure of the Gap Analysis and Issues Log

A simple table format has been used throughout the remainder of this report to log all gaps and issues which need to be addressed within the revised road design guidance for Vanuatu.

The log headings, together with descriptions are provided below in Figure 3.

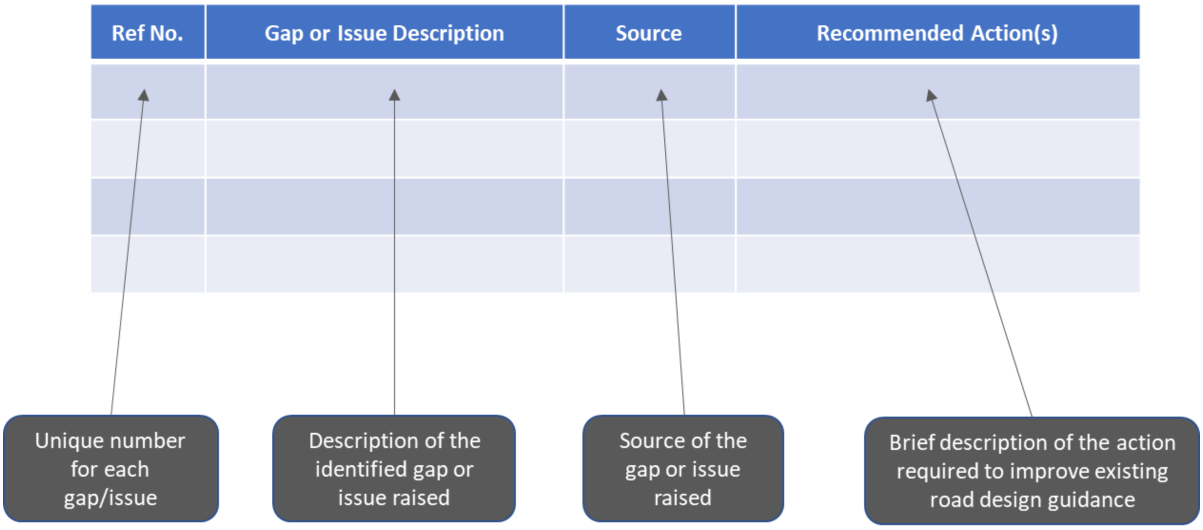


Figure 3: Gap/Issues Log Structure

2. Literature Review Introduction

2.1 Bibliography and References

Annex A contains a list of the international design codes, journals and other climate resilience related literature that have been used to develop the log of gaps and issues. These are cross-referenced where appropriate in the Gap and Issue Analysis Sections 3 to 11.

2.2 General Observations from Literature Review

The main finding from the literature review is that although there is a lot of generalised guidance which urges highway authorities to adopt a risk-based approach to increasing the resilience of roads, there is very little engineering design guidance which specifically addresses the impacts of climate change.

For example, a review of the latest versions of key AASHTO[1] design guides (Policy on Geometric Design 2018, AASHTO Drainage Manual 2014 and Roadside Design Guide 2015) revealed that design guidance has not been updated at all to deal with the impacts of climate change on road assets.

In the UK, the Design Manual for Roads and Bridges, which is published as a series of standalone volumes by the national highway authority, has had one new volume (LA 114) added for climate. This proposes a risk-based approach to the assessment of climate risks during design of infrastructure but does not provide any updated engineering advice. Other engineering design volumes have not been updated for climate resilience.

In Australia, the situation is slightly different, with Australia being ahead of much of the developed world. The Austroads standards, which were used as the basis for the development of the 2017 VRRDG, have been updated to specifically address to climate resilient design. The important 'Part 5 – Drainage' (Edition 2.1, 2023), contains Section 3.2 on climate change. This refers the road designer to the updated 2019 'Australia Roads and Runoff' (ARR) which is updated to reflect future climate change scenarios, represented by Representative Concentration Pathways (RCPs). It is suggested that design criteria should be met for RCP 4.5, with RCP 8.5 used for climate change sensitivity of critical assets since this currently appears to represent the most likely future trajectory. This is consistent with the approach being adopted for Vanuatu's new road design guide.

The overarching conclusion is that in overall terms, very little detailed climate change research has been conducted for the road sector which results in adjusted engineering design guidance. However, there is a lot of policy and process advice, which mostly focuses on the adoption of risk-based approaches to resilient design. Taking the extra step of converting risk assessments to revised engineering design guides has not been undertaken in many countries.

OECD Environment Policy Paper 14 (Climate Resilient Infrastructure) suggests that approaches to climate-resilient infrastructure provision can be grouped into two categories, these being:

- **structural adaptation measures**: e.g., changing the composition of road surfaces so that they do not deform in high temperatures, building seawalls or using permeable paving surfaces to reduce run-off during heavy rainfalls, etc. Ecosystem-based approaches using natural infrastructure to design adaptation measures are also key alternatives to be considered alongside structural adaptation measures, and

---

[1] AASHTO is the American Association of Highway and Transportation Officials of the US.

- **management (or non-structural) adaptation measures:** e.g., changing the timing of maintenance to account for changing patterns, investment in early warning systems or purchasing insurance to address financial consequences of climate variability. These measures can also include enhanced monitoring of existing assets to reduce the risk of failure as climate conditions change. Adaptive management approaches also include provisions to include flexibility from the outset to monitor and adjust to changing circumstances over the asset lifetime.

The new Vanuatu Road Design Guide to be developed under this project will address structural adaptation measures by recommending strengthened approaches to design to create resilient infrastructure, but this reminds us that there is more to be done to improve resilience. Robust approaches specifically tailored for climate change are required for planning, construction, maintenance, disaster recovery processes, capacity development and organisational design to provide an integrated holistic approach to providing resilient infrastructure.

The defining characteristic of climate-resilient infrastructure is that it is planned, designed, built and operated in a way that anticipates, prepares for, and adapts to changing climate conditions. It can also withstand, respond to, and recover rapidly from disruptions caused by these climate conditions. Approaches to climate resilience need to be a continual process throughout the life of the asset, with adjustments made to approaches to suit actual climate conditions and evaluation of climate adaptation efforts.

Throughout the development of the new Vanuatu Road design Guidance, it is important to recognise that climate-resilient infrastructure reduces, but may not fully eliminate, the risk of climate-related disruptions. The extent to which climate change translates into risks for infrastructure depends upon the interaction of changing climate hazards with exposure (the location of assets) and vulnerability (“the propensity or predisposition to be adversely affected”) (Agard & Schipper, 2014). Climate risks to infrastructure can be reduced by locating assets in areas that are less exposed to climate hazards (e.g. avoiding new construction in flood plains), and by making the assets better able to cope with climate impacts when they materialise (e.g., strengthening pavements or providing scour protection).

Such a risk management approach requires making trade-offs between risk minimization and cost. Over design will result in works which are too expensive and technically challenging to construct. Resilience in design means that the risks have been duly considered and designs have been managed to achieve an acceptable level of performance given the available climate information. The costs of protection therefore need to be weighed against the consequences of damage or disruption.

Road designers will state that they have always designed ‘resilient infrastructure’. However, what is now different is that assets must be designed to be resilient in the face of future climate conditions, whereas previously, designers would base designs on historic climate data and conditions. This is particularly true of the assessment of storm flows to inform drainage design, with designers previously able to refer to intensity-duration-frequency curves which were developed from historic data. Designing roads for future climate events requires the designer to rely upon climate predictions, thus introducing significant uncertainty into the design process. Therefore, a risk-based approach to design will be used in the new road design guidance so that critical road assets are prioritised over less critical assets.

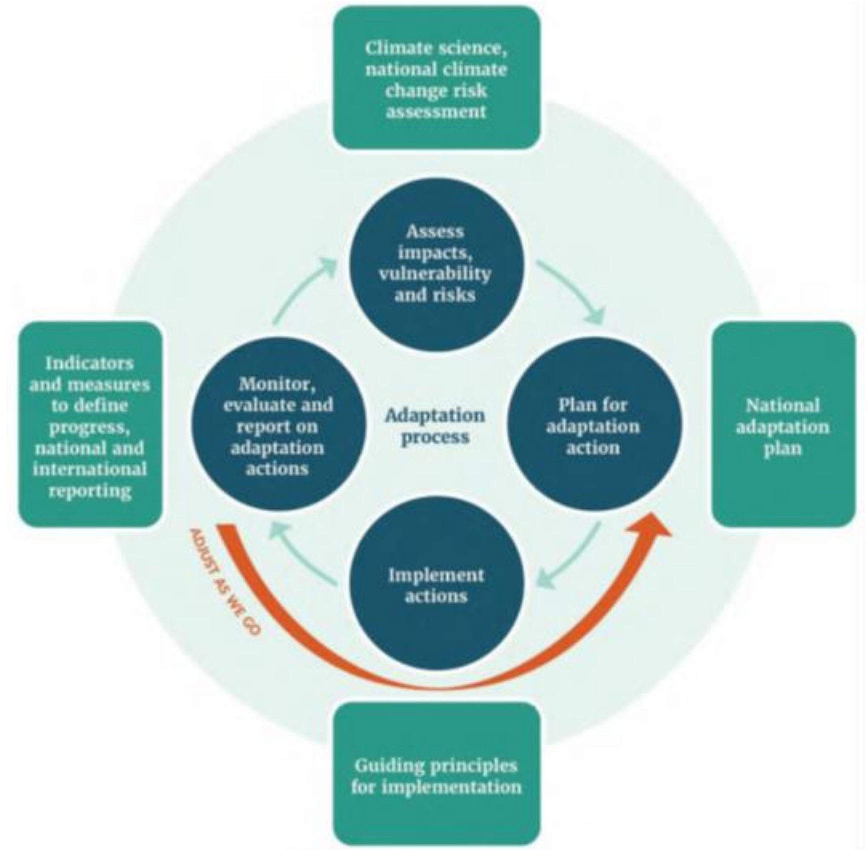
3. General Overarching Gaps and Issues

Ref. No.	Gap or Issue Description	Source	Recommendations for New Road Design Guide
1.1	The VRRDG contains too much descriptive text.	PWD Feedback	Generally reduce text and focus on design requirements only rather than explaining the rationale or academic background to design rules.
1.2	The VRRDG is not presented in a logical order to follow a typical road design sequence.	PWD Feedback	New Road Design Guide to be structured to be easier to follow by providing chapters in a logical design sequence.
1.3	The current design guidance does not cover urban roads.	Project Objectives	The new Road Design Guide will be developed as a generalised design guide to cover all types of roads in Vanuatu, whether in an urban or rural context, and covering all road types mentioned in the 2014 Road Act and in Vanuatu's Public Roads Policy and Public Roads Strategy.
1.4	Some damage is likely to occur during every cyclone and it is impossible to make all road assets completely resilient to cyclone impacts within reasonable and available budget constraints. The Public Roads Strategy sets out a policy of declaring a hierarchy of roads for each island (core roads and non-core roads) and it was suggested that differing degrees of resilience should be assigned to these two classes of road.	PWD and Van-KIRAP Feedback	Different design rules are to be applied to core roads and non-core roads, with core roads designed to withstand climate impacts based upon RCP8.5 predictions and non-core roads based upon RCP4.5 predictions.
1.5	There is a tendency to prioritise expenditure on the road pavement (gravel, concrete, sealed) ahead of drainage and other elements. In some cases, roads are constructed without any consideration of drainage at all.	PWD Feedback	The new Road Design Guide will treat design as a step-by-step process with design engineers responsible for completing the whole process for each section of road design. The new guide will also prioritise drainage design and construction ahead of pavement design and construction to increase the resilience of roads to storm action. Pavements should not be constructed without due consideration of drainage.
1.6	Some PWD Standard Drawings are unclear or incomplete and are not updated to reflect more resilient designs.	PWD Feedback	The PWD Standard Drawings will be updated as a new set of drawings to reflect the new design guide in full.
1.7	The current design guide does not include worked examples.	PWD Feedback	Where appropriate, the new Road Design Guide will include worked examples to demonstrate design principles and rules.

Ref. No.	Gap or Issue Description	Source	Recommendations for New Road Design Guide
1.8	The response to TC Harold included significant short-term recovery work to restore connectivity to essential services such as hospitals, schools, markets and the main commercial centres in the shortest possible time. The expenditure on the emergency phase after one month of operation was in excess of VT40million and at the time of the damage assessment was continuing to increase as clearing operations and emergency repairs were ongoing. The restoration works were estimated to take at least 6 months and the total short-term costs estimates to be around VT108million.	TC Harold Damage Assessment, PWD, May 2020	The TC Harold response shows that post-cyclone repair and restoration works are prioritised on those roads providing connectivity to essential services (hospitals, schools, markets). It therefore makes good economic sense to prioritise resilience improvement efforts on these critical roads. This aligns with the 'core road' concept as described in the Public Roads Policy and Strategy. The new design guide will reflect this prioritisation.
1.9	Community consultations should be a key part of the design approach. Strong community ownership is essential to ensuring longer-term sustainability of investments in the road network, particularly as communities are expected to play a substantial role in future routine road maintenance. As different groups (men, women, those with a disability) may have different needs, the pre-construction engineering designs should be informed by meaningful engagement with communities, and with different groups within the communities, to identify needs, risks, and adaptation measures.	TC Harold Damage Assessment, PWD, May 2020	Although this is not strictly part of a technical design guide, it is important that community consultations take place as part of the design process. Therefore, although the process for undertaking consultations should be detailed elsewhere, the design guide will provide a new section on the key technical issues that should be raised during community consultations.

Ref. No.	Gap or Issue Description	Source	Recommendations for New Road Design Guide
1.10	PWD confirmed, that after TC Harold, all decisions made on the level of intervention must be based on the principle of no regrets. Whatever decision is made should allow for further modifications to be made in the future without excess cost or difficulty. The climate change design interventions should be reviewed every 5 to 10 years.	TC Harold Damage Assessment, PWD, May 2020	The new Road Design Guide will include reasonable resilience in design solutions but subject to sensible budgetary constraints. 'No regrets' does not mean that unlimited funding is available to make all assets 100% resilient. The new design guide will reflect this balanced approach.
1.11	In line with the Public Roads Policy, the 5-year plan targets to achieve 359.7 km of rural and urban core roads sealing under priority 1 works (creating a core road network) for which estimated cost is Vt15.65b. Major maintenance works including resealing of existing roads are planned under priority 2 (maintenance and emergency works) with the estimated cost of Vt2.9b and with the expected output of 187km. The priority 3 works (to increase basic rural access) are intended to improve rural access in the remote islands. New feeder roads and improvement works are planned under Priority 3.	PWD Business Plan and Annual Works Plans 2023 & 2024	The new Road Design Guide should differentiate between those works required to create new roads, upgrade existing roads or maintain existing roads. However, the new guide will not include guidance on how to select the most appropriate projects each year. This should be covered by planning guidance to meet policy and strategy objectives.

Ref. No.	Gap or Issue Description	Source	Recommendations for New Road Design Guide
1.12	Changes in extremes events, such as floods, can be linked to changes in the mean, variance, or shape of probability distributions, or all of these (IPCC, 2012). For example, climate change projections have shown that a relatively small shift in the distribution of precipitation may result in a large change in the frequency and magnitude of extreme precipitation events (Nicholls and Alexander, 2007). Studies have shown that a change in the shape of the distribution of precipitation is likely to have a greater effect on the frequency of extremes than a shift in the mean precipitation (White et al, 2010; Groisman et al., 1999), and that climate change is most likely to increase climate variability, particularly affecting the extremes (Jones et al., 2012; Fowler and Ekstrom, 2009).	Australian Rainfall and Run-Off Book 1 (2019 version)	This warns us that whilst climate change may only be causing modest change to average precipitation, it will cause significant change to the frequency and nature of extreme rainfall events. The new Road Design Guide therefore needs to focus on predicted extremes rather than changes to average temperatures and precipitation.

1.13	Adaptation is a process of assessing risk, planning, implementing, evaluating and adjusting. Adapting to climate change requires a different approach. Natural hazard management has tended to be static and reactive, taking past events as a proxy for their future likelihood and consequences. Climate change is exacerbating the natural hazards we typically experience – making them more frequent and more severe. It is also changing weather patterns in ways that are not necessarily hazardous but are still challenging. Climate-related risk over longer timeframes is inherently uncertain. We must be flexible, so we can change direction as new information and understanding comes to light.	First National Adaptation Plan, Government of New Zealand, 2022	This reminds us that climate adaptation is a process (see figure below). It is a continuous journey of making a plan to assess risks, implementing the plan, monitoring and evaluating how effective the plan is, and adjusting as necessary. The new Road Design Guide should therefore be formally revisited at regular intervals to ensure it remains appropriate for the climate change impacts that occur in say 5 years, 10 years, 15 years, etc. This should include a formal review of the effectiveness of resilience efforts. 

Ref. No.	Gap or Issue Description	Source	Recommendations for New Road Design Guide
1.14	Assessments shall use the H++ climate scenarios to test the sensitivity of vulnerable safety critical features, to ensure that such features will not be affected by more radical changes to the climate beyond that projected in the latest set of UK climate projections. The assessment of a project's vulnerability to climate change shall take the life span of the project to be 60 years.	Design Manual for Roads and Bridges (DMRB), LA 114, Climate, UK. Para 3.30, 3.31	In the UK, a policy has been adopted of testing critical infrastructure elements against the worst-case emissions scenario. A standard 60-year life has been selected for infrastructure vulnerability assessments.
1.15	The UK's DMRB contains a useful table of potential climate change impacts during construction and operation of road assets.	Design Manual for Roads and Bridges (DMRB), LA 114, Climate, UK. Table 3.35N	This has been reproduced in Annex B and may be useful as part of an introduction to the new Road Design Guide.
1.16	PIARC's International Climate Change Adaptation Framework also contains a useful table of potential climate change impacts on road assets.	International Climate Change Adaptation Framework, PIARC (World Road Association), p77, 2015	This has been reproduced in Annex C and may also be useful to inform the introduction to the new Road Design Guide.
1.17	The UK's DMRB proposes a risk assessment of climate impacts using tables which describe 'Likelihood Categories' and 'Measure of Consequence' which are used to determine significance conclusions from a significance matrix.	Design Manual for Roads and Bridges (DMRB), LA 114, Climate, UK. Para 3.39 to 3.41	A similar risk-based method of assessing critical elements of infrastructure should be included in the new Road Design Guide.
1.18	PIARC's International Climate Change Adaptation Framework also contains a similar useful set of probability and severity tables together with guidance and a risk score matrix.	International Climate Change Adaptation Framework, PIARC (World Road Association), p28, 2015	This guidance may also be used to inform a similar risk-based method of assessing critical elements of infrastructure in the new Road Design Guide.

Ref. No.	Gap or Issue Description	Source	Recommendations for New Road Design Guide
1.19	ADB have developed some practical guidance on engineering interventions which may be used to increase the resilience of road assets.	Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects, ADB, 2011.	A summary table from this publication has been included in Annex D. Recommended interventions appropriate for a Vanuatu context include: protection of subsurface conditions, increasing road elevations over waterways, designing drainage for future rainfall conditions and use of protective structures.
1.20	Modern, high volume roads are designed to last from 30 years (pavement structures, excluding the surfacing) to 100 years (major structures) or longer (i.e. long-life pavements). Similarly, low volume engineered earth roads are expected to last between 5 and 6 years with the wearing course of gravel roads between 6 and 10 years, whilst their drainage structures and bridges are expected to last between 50 and 100 years. Low volume paved roads are normally designed for 10 to 20 years. Hence, changes in climate would have to be factored in and considered in the design of all new roads and major rehabilitation projects to equal or improve on the typical life expectancies referred to above.	Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa – Engineering Adaptation Guidelines, ReCAP Project, 2019	This guidance provides a useful reminder of the need to consider different design lives for different types of road asset. His will form part of the approach included in the new Road Design Guide.

1.21	This World Bank Document suggests five pillars of resilience: **Systems Planning:** Risks identification; transport development policy and planning addressing identified risks; shifting development away from disaster-prone areas when possible; consideration of integration and redundancy on critical infrastructure. **Engineering and Design:** Improving design standards of transport infrastructure to maintain connectivity and reduce disaster risk; use of innovative materials and design specifications that enhance robustness and flexibility of infrastructure. **Operations and Maintenance:** Developing asset management systems with mapping of transport assets, improving institutional and financial arrangements; integration of climate and disaster risks in the prioritization of infrastructure investments. **Contingency Programming:** Developing policy frameworks, communication protocols, and investments in emergency preparedness and response; alignment of transport systems and flows with local and regional evacuation, and recovery needs. **Institutional Capacity and Coordination:** Centralizing disaster risk information and data comprehensively; upstream planning of transport systems to reduce the hazard exposure; mitigation of institutional and regulatory challenges, which are cross-cutting in nature, to utilize the life cycle approach effectively.	Low-Carbon and Climate Resilient Transport Infrastructure Development, Mehndiratta, UNCRD 13th EST Forum Plenary Session, World Bank	This reminds us that there is much more to the creation of resilient infrastructure than improved approaches to design. Therefore, although the new Road Design Guide will deal with 'Engineering and Design', the other pillars will also need to be addressed as part of a holistic approach to improving infrastructure resilience.

4. Road Function, Design Speed and Cross-Section

Ref. No.	Gap or Issue Description	Source	Recommendations for New Road Design Guide
2.1	The latest draft PWD Public Roads Strategy which supports the Public Roads Policy sets specific targets and design rules for each type of road.	Public Roads Strategy	Road classifications and geometric design standards will match those quoted in the Public Roads Strategy.
2.2	Cross-sections of some new roads are inadequate and fail to take into account how surface water and subsurface water will be drained from the pavement.	Public Works Department	The new Road Design Guide and standard drawings will place a stronger emphasis on appropriate cross-section design including side drains and allowing pavement layers to drain.
2.3	Engineered earth roads are still constructed from the in-situ materials but these materials are typically moved during the forming of side drains on to the road surface to raise the road above the natural ground level and provide better cross-sectional shape. This results in better drainage of the road surface and enhanced performance.	Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa – Engineering Adaptation Guidelines, Para 5.3.1.2, ReCAP Project, 2019	The good practice of reshaping the ground to bring the road pavement above the surrounding ground level by using material from side drains is recommended in this report. This could be applied to many situations in Vanuatu. The same report also mentions that the crossfall and crown of the road are important factors in increasing resilience.

5. Road Corridor Location

Ref. No.	Gap or Issue Description	Source	Recommendations for New Road Design Guide
3.1	Coastal roads adjacent to the shoreline have been damaged by increased strength of storm surges during storms and cyclones. It is unclear whether sea level rise is also impacting coastal roads. Some roads have already been relocated inland to prevent further damage and avoid inundation.	PWD Feedback	A new section on selection of the location of the road corridor will be introduced. Roads immediately adjacent to the sea will be avoided if alternative alignments are available and feasible.

6. Alignment Design and Road Layout

Ref. No.	Gap or Issue Description	Source	Recommendations for New Road Design Guide
4.1	Alignment designs are often not based upon good topographical survey information.	PWD Feedback	The new Road Design Guide will include details of surveys and other information required to properly inform alignment designs. This will be included at the beginning of the alignment design section.
4.2	Consideration might also be given to elevating low spots (where practical).	TC Harold Damage Assessment, PWD, May 2020	The new Road Design Guide will include advice on how vertical alignments in critical areas should be raised in areas prone to flooding and at significant watercourse crossings.
4.3	Where overtopping of the culvert is likely, low points should be eliminated and the road should be as flat as possible to avoid localised turbulent flow over the embankment. The downstream slope of the embankment over the length of potential overtopping should also be flattened to reduce water velocities and minimise erosion and undercutting.	Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa – Engineering Adaptation Guidelines, ReCAP Project, Para 5.6.2, 2019	This provides good vertical alignment advice to prevent turbulent destructive flows in the event of overtopping of an embankment.

7. Drainage and Slope Design

Ref. No.	Gap or Issue Description	Source	Recommendations for New Road Design Guide
5.1	Drainage designs are often not based upon good topographical survey information.	PWD Feedback	The new Road Design Guide will include details of surveys and other information required to properly inform drainage designs. This will be included at the beginning of the drainage design section.
5.2	Rainfall intensities have been increasing in recent years. The cyclone season appeared to be spreading into April. Rainfall intensities are predicted to increase further in the coming years. Many watercourse/road interface points have been heavily damaged by the action of storm water. Many culverts are undersized and could not cope with the flows generated by recent intense rainfall.	PWD Feedback Van-KIRAP Feedback	The method for the calculation of storm flows at road/watercourse interfaces needs to be adjusted for predicted future increases in rainfall intensity. Different methods will be applied to core and non-core roads. Design rules for sizing of culverts and bridges to deal with calculated flows are to be made clearer in the new Road Design Guide.
5.3	Many major road failures have recently been caused by culverts or bridges becoming blocked due to storm debris being carried along a watercourse.	PWD Feedback	The new Road Design Guide will include a risk assessment process to identify those watercourse crossings which might be prone to the impacts of storm debris. In these cases the size of culverts/bridges will be increased and protection to embankments and pavements will also be increased. In some cases it may be appropriate to clear upstream areas of potential debris.
5.4	Heavy rainfall results in new drainage paths being formed. This causes water to run alongside or along roads causing pavement damage.	PWD Feedback	For core roads, the new Road Design Guide is to include side drains for all lengths of road where such water flows could potentially occur.
5.5	Some gabions baskets had been broken and/or washed away during storms.	PWD Feedback	Gabions in critical locations are to be strengthened with the application of a mortar coat (as practised in PNG).
5.6	Side drains are often undersized.	PWD Feedback	Designs should include a check of side drain flows and result in appropriate sizing of drains.

5.7	Due to the terrain and high rainfall, it is important for road designs and maintenance to emphasize drainage, such as by provision of scour checks, line drains, relief culverts, and outlets and soak away pits. Consideration might also be given to elevating low spots (where practical) and sealing shoulders. Drainage structures should also rely more on in situ building of concrete pipe culverts rather than the use of corrugated pipes, given the aggressive environment and corrosion.	TC Harold Damage Assessment, PWD, May 2020	The new design guide will be based upon the prioritisation of alignment and drainage above the creation of pavement. The design principle to be established is that pavement constructed without adequate drainage is an ineffective and unsustainable investment.
5.8	A revised version of Australia Rainfall and Runoff includes many recent advances in knowledge regarding flood processes, the increased computational capacity available to engineering hydrologists, expanding knowledge and application of hydroinformatics, improved information about climate change and the use of stochastic inputs and Monte Carlo methods. The intention during the development of this new edition was to provide appropriate guidance addressing these issues.	Australian Rainfall and Run-Off Book 1 (2019 version)	The ARR contains very useful detailed guidance on flood estimation in an Australian context taking into account latest climate change prediction models and experience. Some of this may be used in the new road design guide for Vanuatu.
5.9	In Australian Rainfall and Runoff, the Intensity-Frequency-Duration (IFD) Curves presented can be adjusted for future climates using the method outlined in Book 1, Chapter 6. This recommends an approach based on temperature scaling using temperature projections from the CSIRO future climates tool. Scaling based on temperature is recommended, as climate models are much more reliable at producing temperature estimates than individual storm events.	Australian Rainfall and Run-Off Book 2 (2019 version)	This refers to a process for future scaling of intensity-frequency-duration curves based upon temperature change predictions. This may be useful as a method of defining future IFD curves for Vanuatu and will be considered in the development of the new road design guide.

5.10	Austroads recommends basing drainage design on RCP 8.5. In general, where climate change needs to be considered in the design, the result for 2090 will be required most frequently for road design work. The CSIRO guidance as applied in ARR does not extend past 2090, so there is no factor to allow for a longer design life. Major road infrastructure has a design life of 100 years, so extrapolation beyond 2090 is useful. In the absence of any definitive projection, a linear extrapolation is suggested, though this recognises that this suggestion may need change with future changes or climate modelling.	Guide to Road Design Part 5, Austroads Standards, 3.2.4	If required, this section provides a suggested method for extrapolating predictions beyond the end date of available predictions. This may be useful in the new Road Design Guide.
5.11	A useful decision tree for incorporating climate change into flood design is provided in Figure 3.3	Guide to Road Design Part 5, Austroads Standards, 3.2.2	A similar approach, perhaps adapted for Vanuatu, will be incorporated into the new Road Design Guide.
5.12	In the context of design flood estimation, examples of deep uncertainty could include the effects of climate change, because the different scenarios used for future greenhouse gas emissions are uncertain and cannot be assigned probabilities.	Guide to Road Design Part 5, Austroads Standards, 6.13.2	This is a reminder that the estimation of floods and storm flows is subject to significant uncertainty. This needs to be made clear in the new Road Design Guide. Storm flow estimation at road/watercourse interfaces is not an exact science as many variables and uncertainties are involved.
5.13	Flood Resilience: Floods larger than the design flood may occur, so there should be at least some consideration of what may happen during such events. While the road drainage network cannot be expected to perform well during a very rare event with parts of it being completely under water, a resilient design should not suffer total failure or extreme damage of large sections in these events.	Guide to Road Design Part 5, Austroads Standards, 6.9.2	This is a reminder that although we can design for a ‘design’ flood or storm flow, there may be occasions, due to the many uncertainties and inaccuracies involved in predicting storm run-off, that the affected road asset(s) will be required to deal with an extreme event greater than the design storm. Thinking about how road assets will perform in this extreme situation is important to maximise resilience.

5.14	The 'Strengthening the Resilience of Small Scale Rural Infrastructure (SSRI) and Local Governance Systems to Climate Variability and Risks' project in Timor-Leste worked to strengthen and protect physical infrastructure by using techniques such as soil bioengineering where plants with long roots are used to stabilize the soil against erosion and landslides.	Strengthening the Resilience of Small Scale Rural Infrastructure (SSRI) and Local Governance Systems to Climate Variability and Risks', Timor Leste, UNDP	Planting of unstable slopes to improve resilience against landslips should be considered in appropriate areas.
5.15	An increase in 100-year rain events, increased soil moisture and higher resulting groundwater tables, and/or increases in mean rainfall will cause more landslides requiring extensive repairs and causing closure of roads for short or extended periods.	Climate Change Effects on the Land Transport Network Volume One: Literature Review and Gap Analysis, NZ Transport Agency Research Paper 378, 6.4.2.	This provides a reminder that prolonged storms can also increase moisture content and heighten water tables thus increasing the risk of local landslides or slips. Critical slopes will therefore require additional protection.
5.16	The main climate impacts on unpaved roads are related to the presence of excessive water on the road surface and within the pavement structure. The impact is also strongly related to the duration and intensity of the precipitation.	Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa – Engineering Adaptation Guidelines, Para 5.3.1, ReCAP Project, 2019	This is a reminder that the impact of subsurface water on the pavement structure is a critical factor in achieving resilience.
5.17	Residents (Himalaya Times, 2016) have indicated that the "haphazard use of heavy equipment for road construction has brought problems; elsewhere; national and community forests are being destroyed for road construction projects". It should be borne in mind that uncontrolled excavation at the toes of high natural slopes and the lack of appropriate surface and sub-surface drainage will inevitably lead to slope instability.	Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa – Engineering Adaptation Guidelines, Para 5.3.3, ReCAP Project, 2019	The new design guide must include guidelines on controlled and stable slope excavation. During the investigation and design of new road slopes, an assessment of potential slope instability problems should be made. This involves a review of the topography, geology, soil and rock properties and weathering, surface and groundwater drainage and inspection of existing slopes and past instability history in the area and is best carried out by a geotechnical or engineering geological specialist.

5.18	When assessing embankments for adaptation measures, it is important to identify the potential water paths and approach angles (water approaching perpendicularly is easier to control than water approaching at a more acute angle), whether the water will flow over the embankment and the impact of the water on the embankment materials. In areas where erosion of the embankment is likely, the installation of rip-rap protection is necessary or flatter vegetated side-slopes can in many cases prevent damage. However, if the local materials are liable to be easily eroded, the rip rap should be grouted and measures taken to ensure that the water cannot enter the embankment from above and especially behind the erosion protection. It is also necessary to include "weep-holes" that allow water that does inadvertently get behind erosion protection measures to escape without permitting water to enter these holes.	Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa – Engineering Adaptation Guidelines, Para 5.3.3.2, ReCAP Project, 2019	This provides guidance on strengthening the protection of embankment slopes which are at risk of storm damage. Grouted rip rap should be used to protect such slopes and it should extend across the full length likely to be affected by storm water. The document also suggests that embankments at major watercourses should be designed for overtopping. Embankments which are fully compacted will be more resilient.
5.19	Some form of vegetation should be used on all roadway slopes that will accept plant growth. Such vegetation should ideally be resilient to anticipated changes in temperature and rainfall. Slopes should also be designed as far as possible to encourage vegetation, usually at batters less than 1V:1.5H. The vegetation helps to reinforce the soil, prevents excess erosion and reduces water impacts, runoff velocities and friction.	Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa – Engineering Adaptation Guidelines, Para 5.3.3.3, ReCAP Project, 2019	This document provides guidance on the treatment of side slopes with vegetation to improve resilience. The report suggests that local deep-rooted grasses should be used as far as possible but certain vegetation types (e.g. vetiver grass (chrysopogon zizanioides), a native to India), is particularly useful and is used internationally. It is a non-invasive, bunchgrass whose roots can penetrate between 2 and 4 m deep and is thus able to bind soil and resist erosion.

5.20	Within side drains, should scour be unavoidable due to material and topographic constraints, the installation of scour checks or even concrete or mortared stone linings in the drain should be considered. Scour checks should be spaced such that the water in the drains does not build up a high velocity, with typical spacings of about 5 m on steeper gradients (>10%) and about 15 m on gradients less than about 5%.These can be very simple installations consisting of, for example, a pegged down log to sophisticated gabion baskets, palisades, grassed water ways, brush layering, bamboo fencing, wattle fencing, and similar measures depending on the situation.	Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa – Engineering Adaptation Guidelines, Para 5.5.2, ReCAP Project, 2019	This provides guidance on the use of scour checks in side drains to prevent excessive scour within the drain. This will be less expensive than full ditch lining.
5.21	In large catchment areas, the use of upstream flood-control dams and structures (usually in cooperation with other national agencies) should be considered to try and minimise the effects of storms where doubt exists in the calculation of the flow volumes. This could be considered as part of water harvesting operations.	Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa – Engineering Adaptation Guidelines, Para 5.6.2, ReCAP Project, 2019	This recommendation may be very useful for some critical watercourses. If opportunities exist for upstream works to minimise flows at road/watercourse interfaces, these should be explored.

8. Design of Structures

Ref. No.	Gap or Issue Description	Source	Recommendations for New Road Design Guide
6.1	Where culverts were overtopped during storms, embankments and watercourse were often badly scoured leaving structural foundations undermined and exposed.	PWD Feedback	Improve resilience of major culverts through: use of return walls as well as wing walls, deeper cut-off walls (upstream and downstream) and appropriate embankment protection.
6.2	Bridge decks were not always set above flood level (resulting in a Bailey bridge deck being washed away in Tanna).	PWD Feedback	Bridges should be designed with a reasonable factor of safety built into the setting of the underside of deck height through the setting of a minimum freeboard for different bridge types. A reasonable assessment of maximum flood level height will need to be undertaken at each bridge crossing to achieve this.
6.3	Drifts provide a more resilient solution than culverts for small watercourse crossings of roads. Drifts are particularly useful for roads in low-lying areas.	PWD Feedback	For low-volume roads crossing small watercourses, drifts should be used instead of a culvert. Extending concrete pavements further to either side of a drift will further improve resilience.
6.4	There are many guidelines and codes available for the design and construction of larger structures using concrete and steel, such as Overseas Road Note 9 (TRL, 2000). However, little guidance is generally available concerning small structures. In this respect, the guideline document Small Structures for Rural Roads: A Practical Planning, Design, Construction & Maintenance Guide (Larcher et al, 2010) provides comprehensive information to assist engineers and technicians in the planning and provision of small road structures.	Small Structures for Rural Roads - A Practical Planning, Design, Construction & Maintenance Guide (Larcher et al, 2010), Global Transport Knowledge Partnerhsip, DfID, UK	This guide provides very good practical advice and drawings covering the construction of small scale structures for rural roads. Many of the recommended details may be useful for updating the new Road design Guide and for updating PWD standard drawings.

9. Design of Pavements

Ref. No.	Gap or Issue Description	Source	Recommendations for New Road Design Guide
7.1	Gravel pavements, if subjected to significant water flows during storms, are generally not resistant to scour in Vanuatu. This is primarily due sub-standard grading of the gravel mix. Storm damage to gravel roads occurs more frequently on gravel roads which do not have side-drains or where side-drains had been filled or blocked.	PWD Feedback	The new Road Design Guide should include a side drain (or drains) as standard for most gravel roads. More attention needs to be paid to the grading of gravel mixes. Potholes which appear soon after opening should be filled quickly to avoid further deterioration. Attention needs to be paid to adequate crossfalls to avoid water sitting on the pavement surface which causes softening.
7.2	Many DBST roads are failing soon after opening. A good quality DBST road should last between 5 to 10 years. Some sections of DBST had suffered edge damage due to water scour during storms.	PWD Feedback	The new Road Design Guide to ensure DBST pavements are protected with adequate drainage. Although not related to design, the quality of DBST construction needs to be improved.
7.3	In some cases, heavy rainfall causes water to flow along or alongside steep sections of road, especially where road pavements have been formed of concrete. This has resulted in significant damage to embankments and road pavements at the foot of the slope, especially if water flowed across the road at this point.	PWD Feedback	Concrete pavements should be extended at the foot of slopes to include the zone where water may cross the road or cause edge damage to the road pavement.
7.4	Where culverts were overtopped during storms, lengths of non-concrete pavement were scoured or washed out.	PWD Feedback	Lengths of concrete pavement either side of each culvert location would improve resilience significantly as washout of the road pavement would be avoided or at least reduced.
7.5	Consideration might be given to sealing shoulders in areas where edge damage to pavements might be expected.	TC Harold Damage Assessment, PWD, May 2020	The new Road Design Guide will include advice on where sealing shoulders might be useful to improve resilience.
7.6	Reference to other climate adaptation projects reminds us that paving or sealing road segments will reduce dust in the dry months but could also increase	ADB Rural Roads Improvement (RRP CAM 42334) Climate Change	An assessment of additional runoff needs to be considered in the design of paved or sealed pavements.

	runoff to surrounding areas during rainy seasons. Measures to manage this increased runoff, especially with increased peak rainfall events and storms, need to be built into adaptation measures.	Adaptation Component – Design Report.	
7.7	A gravel road should consist of a properly shaped structure, raised above the natural ground level to an extent that allows suitable cross-drainage structures. In addition to this, appropriate side and mitre drains (turn-outs) should be constructed and a wearing course gravel complying with certain criteria should be placed on top of the pavement structure, with or without an underlying "subbase" depending on the quality of the supporting layers. The wearing course must be placed, compacted to an appropriate density and shaped with a 4 to 5% cross-fall to ensure good drainage from its surface. Without any of these inputs, the selected material, no matter how good it is, will be rapidly lost under traffic and climatic effects, as seen in many Sub-Saharan Africa countries.	Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa – Engineering Adaptation Guidelines, Para 5.3.1.3, ReCAP Project, 2019	This is a reminder that gravel roads, if not constructed carefully, using appropriate sub-base, base and wearing course materials, will soon be lost. This guidance also suggests that all gravel roads should be elevated to a level which allows cross-drainage structures.
7.8	A properly designed and constructed gravel roads with appropriate wearing course materials should be able to withstand even the most severe climatic effects, except for those on steep gradients where they could be impacted by erosion.	Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa – Engineering Adaptation Guidelines, Para 5.3.1.3, ReCAP Project, 2019	This report recommends that gravel roads are not used on steep gradients. The new Road Design Guide must therefore include guidance on which gradients are unsuitable for gravel.
7.9	In areas with the potential for increased rainfall, it will be important to avoid pavement designs that produce a "bath-tub" effect, i.e. where the pavement structure is more permeable than the surrounding layers resulting in accumulation of water in the structural layers of the pavement and the development of high pore-water pressures under	Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa – Engineering Adaptation	This reminds us of the importance of ensuring sub-base, base and wearing course layers can be drained by selection of an appropriate cross-section and alignment.

	traffic loading. This is best done by ensuring that pavement layers (particularly base and subbase) continue to the edge of the embankment and are not terminated under the edge of the paved area.	Guidelines, Para 5.3.2.1, ReCAP Project, 2019	
7.10	It is recommended that surfacings consisting of discrete elements are not used in areas that are likely to be subjected to flooding or overtopping by rivers resulting from increased rainfall or more frequent extreme events. They can be used in the approach areas but concrete pavements are typically the best alternative in the actual areas likely to be flooded.	Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa – Engineering Adaptation Guidelines, Para 5.3.2.4, ReCAP Project, 2019	This suggests that forms of pavement such as cobbles or blocks should not be used in areas which are at risk of flooding.

Annex A – Bibliography - International Benchmarking Sources

to be completed in final version

Author Surname	Author Initial	Year	Article Title	Journal Name	Volume (Issue)	Page Range

Annex B – Table 3.35N reproduced from UK Design Manual for Roads and Bridges

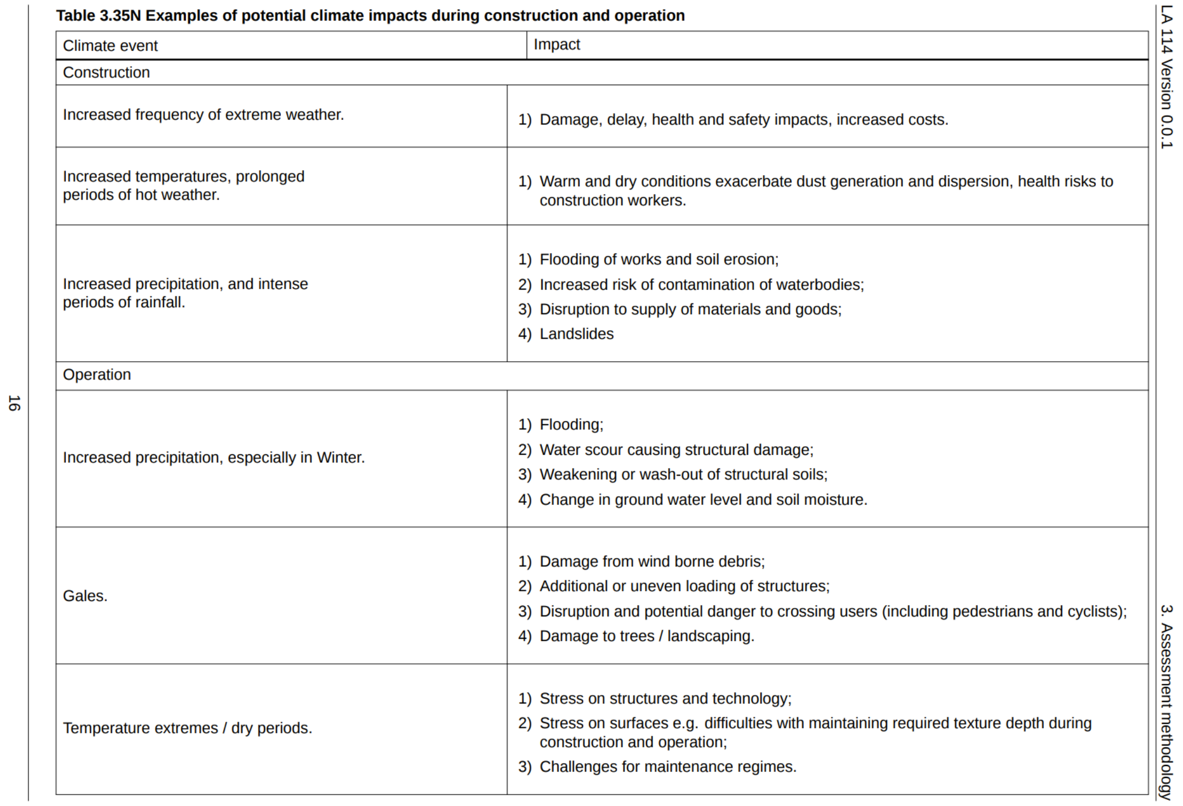


Table 3.35N Examples of potential climate impacts during construction and operation

Climate event	Impact
Construction	
Increased frequency of extreme weather.	1) Damage, delay, health and safety impacts, increased costs.
Increased temperatures, prolonged periods of hot weather.	1) Warm and dry conditions exacerbate dust generation and dispersion, health risks to construction workers.
Increased precipitation, and intense periods of rainfall.	1) Flooding of works and soil erosion; 2) Increased risk of contamination of waterbodies; 3) Disruption to supply of materials and goods; 4) Landslides
Operation	
Increased precipitation, especially in Winter.	1) Flooding; 2) Water scour causing structural damage; 3) Weakening or wash-out of structural soils; 4) Change in ground water level and soil moisture.
Gales.	1) Damage from wind borne debris; 2) Additional or uneven loading of structures; 3) Disruption and potential danger to crossing users (including pedestrians and cyclists); 4) Damage to trees / landscaping.
Temperature extremes / dry periods.	1) Stress on structures and technology; 2) Stress on surfaces e.g. difficulties with maintaining required texture depth during construction and operation; 3) Challenges for maintenance regimes.

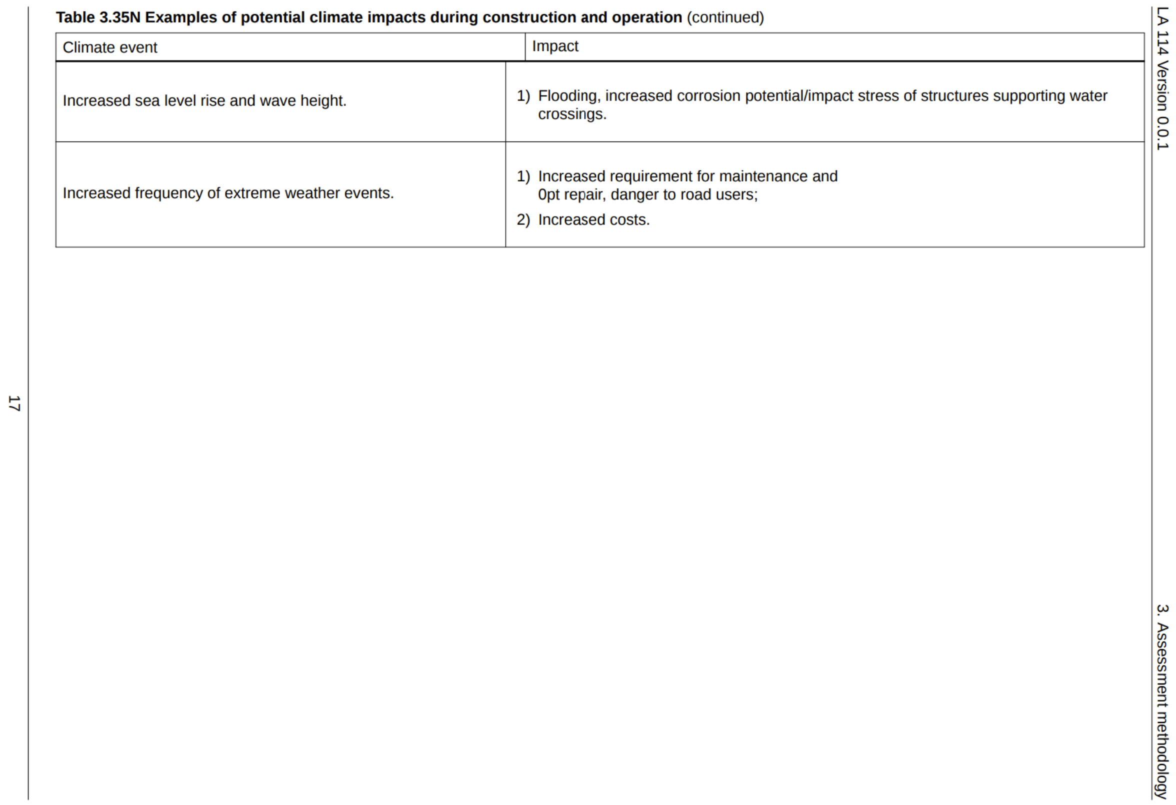
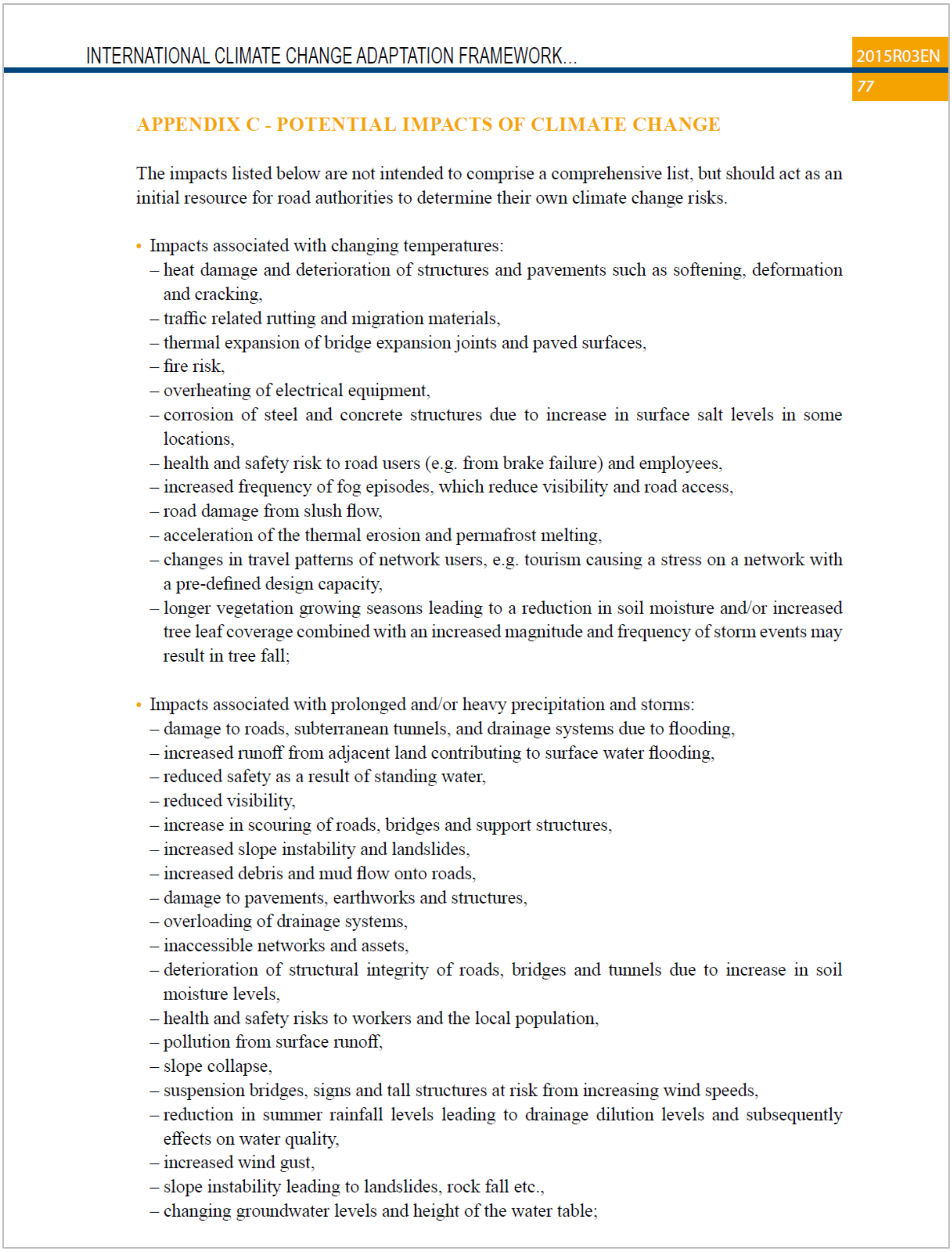


Table 3.35N Examples of potential climate impacts during construction and operation (continued)

Climate event	Impact
Increased sea level rise and wave height.	1) Flooding, increased corrosion potential/impact stress of structures supporting water crossings.
Increased frequency of extreme weather events.	1) Increased requirement for maintenance and 0pt repair, danger to road users; 2) Increased costs.

Annex C – Table 3.35N reproduced from UK Design Manual for Roads and Bridges

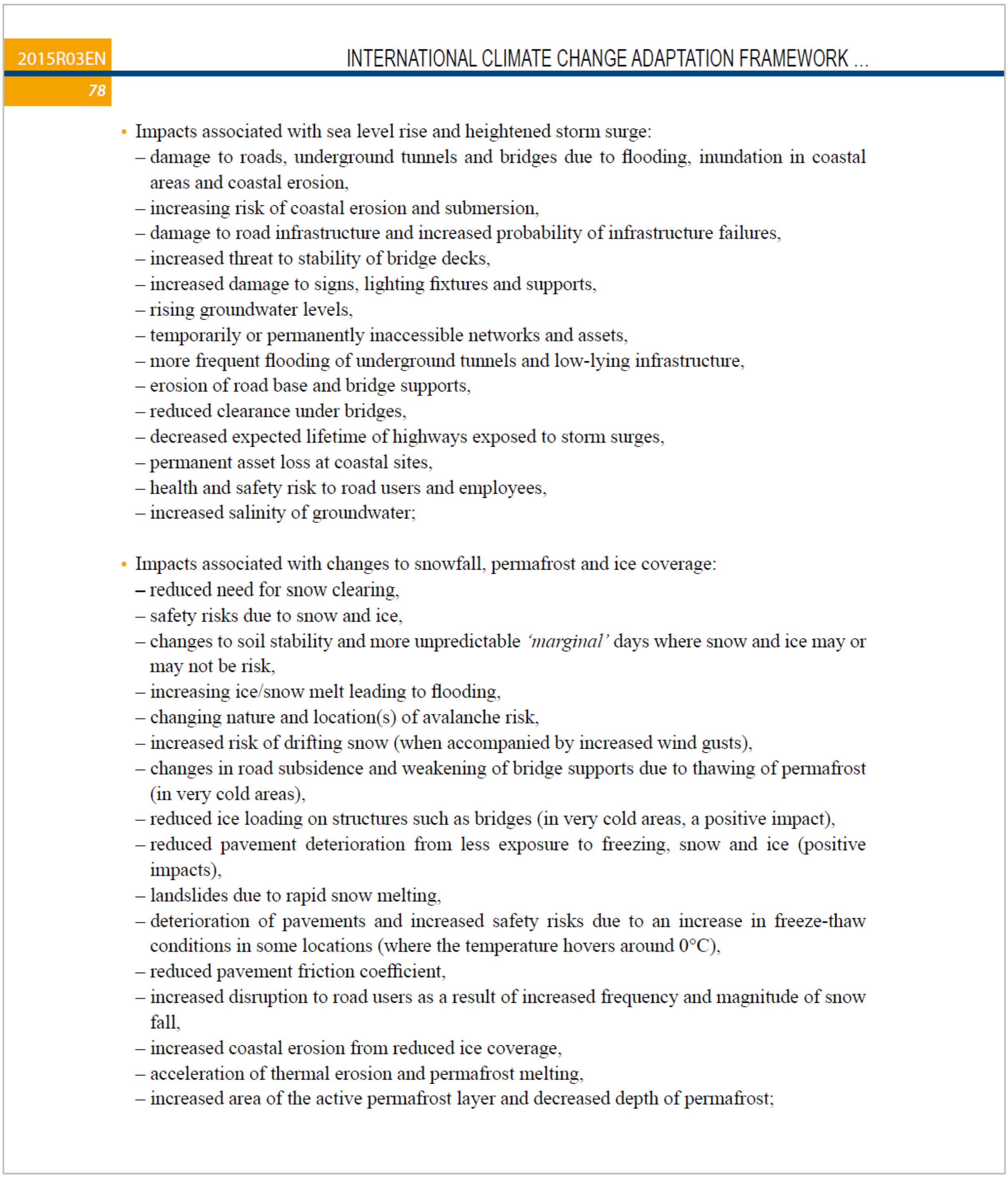


APPENDIX C - POTENTIAL IMPACTS OF CLIMATE CHANGE

The impacts listed below are not intended to comprise a comprehensive list, but should act as an initial resource for road authorities to determine their own climate change risks.

- Impacts associated with changing temperatures:
  - heat damage and deterioration of structures and pavements such as softening, deformation and cracking,
  - traffic related rutting and migration materials,
  - thermal expansion of bridge expansion joints and paved surfaces,
  - fire risk,
  - overheating of electrical equipment,
  - corrosion of steel and concrete structures due to increase in surface salt levels in some locations,
  - health and safety risk to road users (e.g. from brake failure) and employees,
  - increased frequency of fog episodes, which reduce visibility and road access,
  - road damage from slush flow,
  - acceleration of the thermal erosion and permafrost melting,
  - changes in travel patterns of network users, e.g. tourism causing a stress on a network with a pre-defined design capacity,
  - longer vegetation growing seasons leading to a reduction in soil moisture and/or increased tree leaf coverage combined with an increased magnitude and frequency of storm events may result in tree fall;

- Impacts associated with prolonged and/or heavy precipitation and storms:
  - damage to roads, subterranean tunnels, and drainage systems due to flooding,
  - increased runoff from adjacent land contributing to surface water flooding,
  - reduced safety as a result of standing water,
  - reduced visibility,
  - increase in scouring of roads, bridges and support structures,
  - increased slope instability and landslides,
  - increased debris and mud flow onto roads,
  - damage to pavements, earthworks and structures,
  - overloading of drainage systems,
  - inaccessible networks and assets,
  - deterioration of structural integrity of roads, bridges and tunnels due to increase in soil moisture levels,
  - health and safety risks to workers and the local population,
  - pollution from surface runoff,
  - slope collapse,
  - suspension bridges, signs and tall structures at risk from increasing wind speeds,
  - reduction in summer rainfall levels leading to drainage dilution levels and subsequently effects on water quality,
  - increased wind gust,
  - slope instability leading to landslides, rock fall etc.,
  - changing groundwater levels and height of the water table;



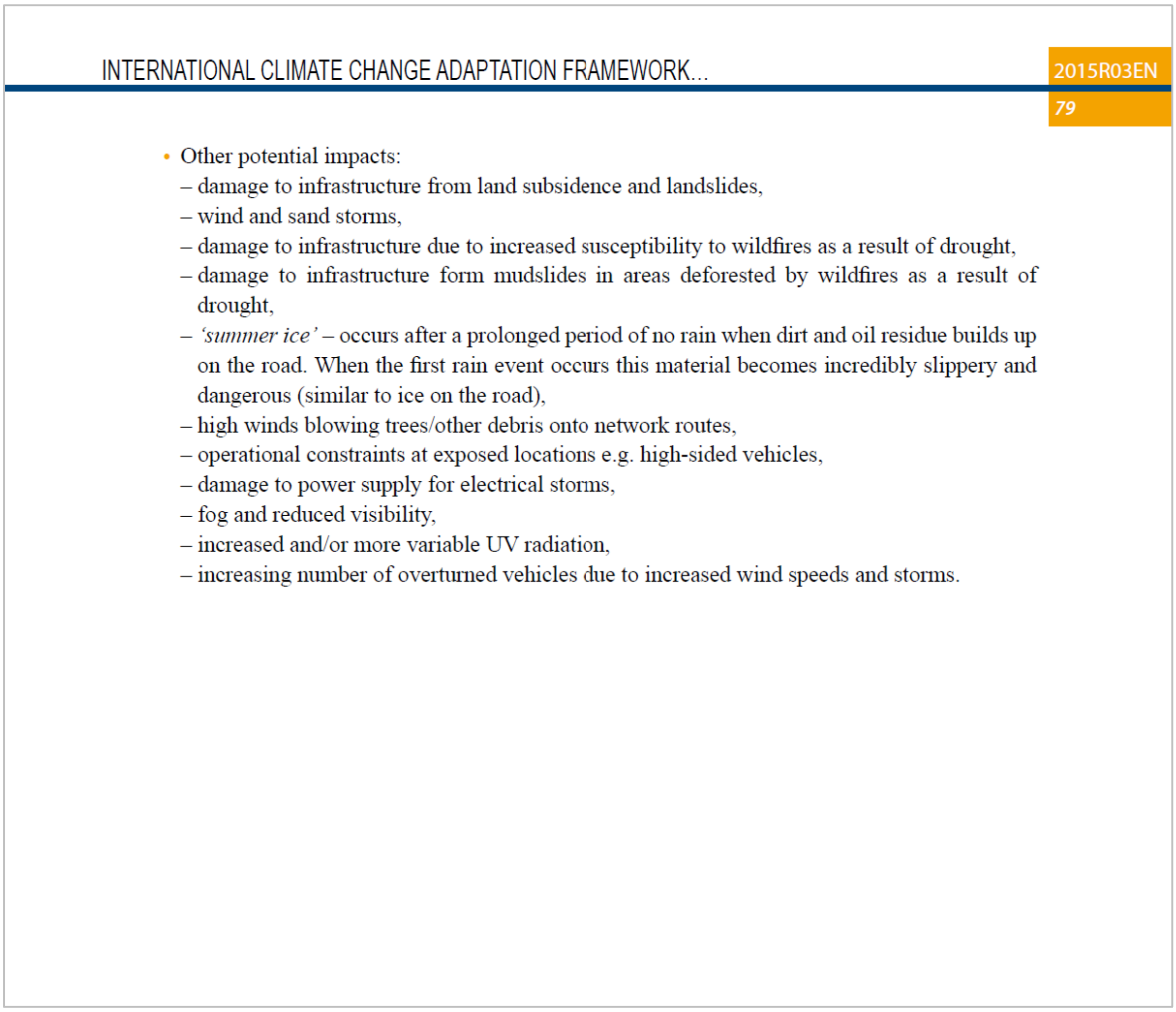
2015R03EN

INTERNATIONAL CLIMATE CHANGE ADAPTATION FRAMEWORK ...

78

- Impacts associated with sea level rise and heightened storm surge:
  - damage to roads, underground tunnels and bridges due to flooding, inundation in coastal areas and coastal erosion,
  - increasing risk of coastal erosion and submersion,
  - damage to road infrastructure and increased probability of infrastructure failures,
  - increased threat to stability of bridge decks,
  - increased damage to signs, lighting fixtures and supports,
  - rising groundwater levels,
  - temporarily or permanently inaccessible networks and assets,
  - more frequent flooding of underground tunnels and low-lying infrastructure,
  - erosion of road base and bridge supports,
  - reduced clearance under bridges,
  - decreased expected lifetime of highways exposed to storm surges,
  - permanent asset loss at coastal sites,
  - health and safety risk to road users and employees,
  - increased salinity of groundwater;

- Impacts associated with changes to snowfall, permafrost and ice coverage:
  - reduced need for snow clearing,
  - safety risks due to snow and ice,
  - changes to soil stability and more unpredictable *'marginal'* days where snow and ice may or may not be risk,
  - increasing ice/snow melt leading to flooding,
  - changing nature and location(s) of avalanche risk,
  - increased risk of drifting snow (when accompanied by increased wind gusts),
  - changes in road subsidence and weakening of bridge supports due to thawing of permafrost (in very cold areas),
  - reduced ice loading on structures such as bridges (in very cold areas, a positive impact),
  - reduced pavement deterioration from less exposure to freezing, snow and ice (positive impacts),
  - landslides due to rapid snow melting,
  - deterioration of pavements and increased safety risks due to an increase in freeze-thaw conditions in some locations (where the temperature hovers around 0°C),
  - reduced pavement friction coefficient,
  - increased disruption to road users as a result of increased frequency and magnitude of snow fall,
  - increased coastal erosion from reduced ice coverage,
  - acceleration of thermal erosion and permafrost melting,
  - increased area of the active permafrost layer and decreased depth of permafrost;



INTERNATIONAL CLIMATE CHANGE ADAPTATION FRAMEWORK…

2015R03EN

79

- Other potential impacts:
  - damage to infrastructure from land subsidence and landslides,
  - wind and sand storms,
  - damage to infrastructure due to increased susceptibility to wildfires as a result of drought,
  - damage to infrastructure form mudslides in areas deforested by wildfires as a result of drought,
  - *'summer ice'* – occurs after a prolonged period of no rain when dirt and oil residue builds up on the road. When the first rain event occurs this material becomes incredibly slippery and dangerous (similar to ice on the road),
  - high winds blowing trees/other debris onto network routes,
  - operational constraints at exposed locations e.g. high-sided vehicles,
  - damage to power supply for electrical storms,
  - fog and reduced visibility,
  - increased and/or more variable UV radiation,
  - increasing number of overturned vehicles due to increased wind speeds and storms.

Annex D – Extract from Asian Development Bank (2011) Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects

Box 8 - Road Infrastructure Projects Interventions[40]

Engineering/ Design Standard Interventions:

- **Subsurface conditions**: The type, strength, and protection of subsurface conditions and materials may have to be increased to control and prevent soil saturation from damaging infrastructure. The composition of the subsurface materials can be adjusted to account for changing climatic conditions. Availability of water for compaction during construction may be an issue in some areas where rainfall is projected to diminish. Melting permafrost may also be a critical factor in some countries.
- **Material specifications**: The strength of materials may have to be increased to withstand increased or decreased moisture contents. The protection of these materials may have to be enhanced to preserve the expected lifetime of the structure, or other materials may need to be used. For example, because of increased salinity, steel reinforcements and culverts may be replaced with less corrosive materials.
- **Cross section and standard dimensions**: For example, standards may need to be revised to increase the slope of pavement in areas where one can expect a need to remove more water from the road. Similarly, standards (or guidelines) pertaining to road elevations or the vertical clearance of bridges over waterways may have to be revised upward to withstand more extreme flood conditions.
- **Drainage and erosion**: Attention must be paid to standard designs pertaining to drainage systems, open channels, pipes, and culverts to reflect changes in future expected runoff or water flow. Further, it may be appropriate to include a provision for use of superfluous drainage water for domestic or irrigation purposes.
- **Protection engineering structures**: Protective engineering structures can be used to fend off rising sea levels and storm surges. These may include dikes, seawalls, rocky aprons, breakwater systems, and other structures. Retaining walls can also be planned for areas where land and mudslides are increasing, with the same caveat that reducing the causes of such events in the first place may be more effective.

---

[39] Institut Des Routes, des Rues et des Infrastructures pour la Mobillité. The TRACC EXPERT Project. Available at: *http://www.idrrim.com/comites-operationnels_groupes_travail-idrrim/methodologie/groupe-national-tracc-expert/*

[40] Asian Development Bank (2011). Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects. Available online at: *http://www.adb.org/documents/guidelines-climate-proofing-investment-transport-sector-road-infrastructure-projects*

7Dee Consult

5 Portia Road
Stratford upon Avon
CV37 0AR
United Kingdom

SPREP
Secretariat of the Pacific Regional
Environment Programme